Real Time Monitoring of Driver Drowsiness and Alertness by Textile Based Nanosensors and Wireless Communication Platform

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***Abstract*—Drowsiness and its effect on driver impairment is one of the major factors of accidents or vehicle crashes. A myriad of systems in the engineering discipline have been developed to monitor drowsiness and fatigue in a driver. However, statistics from the NHTSA (National Highway Traffic Safety Administration), FMCSA (Federal Motor Carrier Safety Administration) and CDC (Center for Disease Control and Prevention) exemplify a need to develop techno-efficient systems to monitor drowsiness in a driver. Pursued researches and commercially available systems supplicate the demands of this field. Varied approaches like bio potential signal methods, image recognition techniques, behavior detection strategies, driving habit approaches are a few methods used to detect drowsiness. Conventionally, the bio-potential-signal approaches have provided better technological breakthroughs in terms of efficiency and have alleviated ill-effects. Consequently, this paper proposes a system based on the electroencephalogram (EEG) and electrooculogram (EOG) type of information to discriminate drowsiness and attentiveness. To monitor the EEG and EOG, development of a flexible headband equipped with a textile-based analog sensor and a signal processing unit is proposed. The sensor acts an electrode to acquire bio potentials from the frontal cortex of the forehead, and is electrically transmitted to the processing unit through conductive threads, where the signal is processed and transmitted through a Bluetooth communication module. The transmitted signal is received in a monitoring unit, where the signals are further processed and classified to detect drowsiness. This paper focuses on monitoring drowsiness in a driver, since the statistics reveal that people are affected the most because of drowsiness during driving than performing other tasks.**

***Index Terms*—Drowsiness, EEG, EOG, Real time monitoring, Bluetooth and Textile electrode.**

I. INTRODUCTION

Approximately 100,000 crashes occur annually because of the fatigued drivers [1]. Statistics [2] from the Sleep in America poll conducted by the National Sleep Foundation states that around 168 million people, annually, have felt drowsy while they were driving. Further breakdown of the statistics indicate that approximately 11 million drivers admit that they faced an accident or were about to face an accident because of drowsiness. Additionally, 1,500 deaths, 71,000 injuries and $12.5 billion monetary losses is another statistic reported annually by the National Highway Traffic Safety Administration [3]. Thus, there is an evident need to prevent drowsy driving and accidents caused by it. There are several techniques and methods, such as medical and drug intakes, maintaining proper sleep cycles, pre-driving sleep evaluation tests, and so on, that have been adopted to address the above problem. However, it would be highly desirable to develop a system which detects sleep and drowsiness readily under all conditions to effectively prevent the ill effects of drowsy driving. Similarly, if available, a system which can be used for aftermath analysis of any accident would provide more information that would be helpful for studies pertaining to the prevention of accidents. As indicated in Figure 1, approximately 40 % of the people in the age group of 30-64 have been reported falling asleep on the wheels, which also is the age group where maximum people drive [1].

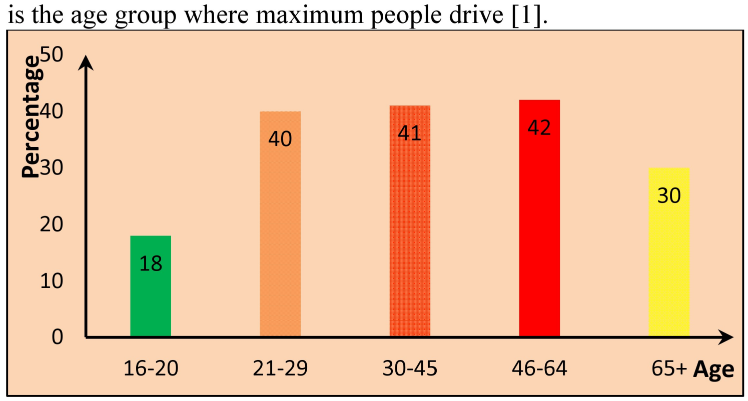

Figure 1: Percentage of people nodding off while driving with respect to age

A World Health Organization research shows that the driver's fatigue can be equally dangerous as being intoxicated. The system proposed herein uses bio-potential signals EEG and EOG to monitor the driver's fatigue and sleep condition and is also used to detect the mentioned parameters. Alpha (8-13 Hz) and beta (13-30 Hz) waves indicate relaxation and attentiveness respectively. This feature from the EEG signal is correlated to the blink patterns (closed eyes, open eyes, normal blinking and slow blinking) obtained from EOG signal, which provides a healthy assumption to detect drowsiness efficiently. In view of the very low frequency range of the bio potentials, both the EEG and EOG signals are transformed from the time domain to frequency domain using a software module for more accurate processing. A headband equipped with sensors is fabricated and utilized as the front end of the system. This headband detects the raw bio-potential signals via the embedded sensors and sends those detected signals to the processing unit. The processing unit then converts the raw signals into signals from which meaningful information can be extracted. The processing unit has the ability to convert the raw analog signals into digital signals with the help of a microprocessor and A/D (Analog to Digital) converter. The processing unit is also equipped with a Bluetooth wireless communication module, which can send data to a remote location, which also enables real-time monitoring and detection of a driver's sleepiness. The entire system is powered by a lithium-ion battery which is rechargeable. The back end of the module consists of software at the receiver end, which is programmed to extract the features from the EEG and EOG signals. Specific features from which sleep can be detected, are correlated in the software and it emits a warning signal whenever the driver shows a tendency to fall asleep. The eye blinks from the EOG signal and the AR-PSD (Auto Regressive-Power Spectral Density) value of the brain signal in the alpha frequency band are correlated to estimate the condition of the driver.

The work presented in this paper describes the real-time driver-alertness monitoring system as an outcome of the research pursued by the authors. A real-time monitoring system was built to evaluate the condition of the driver during driving. All three modules, namely a flexible headband, hardware module and a software module were designed, developed and validated to implement a practical version of the proposed real-time alertness monitoring system. A survey of other research methods and methodologies followed by various research groups were carefully analyzed and a "best effort" was made to improve the currently available monitoring methods, tracking techniques and processing methodologies [4,5], and a detailed elucidation of the complete system and its modules is included in the paper, which also mentions the issues relevant to this prototype system that would be useful to know for future embellishments of system. Figure 2 gives a pictorial representation of the system and the technological process flow involved.

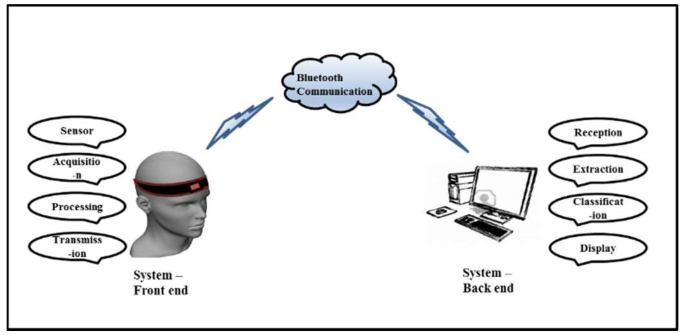

Figure 2: Pictorial representation of the system

II. HARDWARE DEVELOPMENT

Headband architecture

The commercially available sports headband is used to mount the sensor and the electronics. Additionally this flexible headband is also used by the electrode to provide sufficient pressure in exerting an adequate contact with the frontal cortex of the brain, from where the EEG and EOG signals are acquired. The electrode is stitched in the headband where it contacts the forehead. The electrode is electrically connected to the electronics module by the conductive thread stitched through the headband. The bio potential signals acquired through the electrode is electrically conducted to the signal processing module where they are amplified, digitized and transmitted to the receiver [6]. Figure 3 shows the textured layers of the headband.

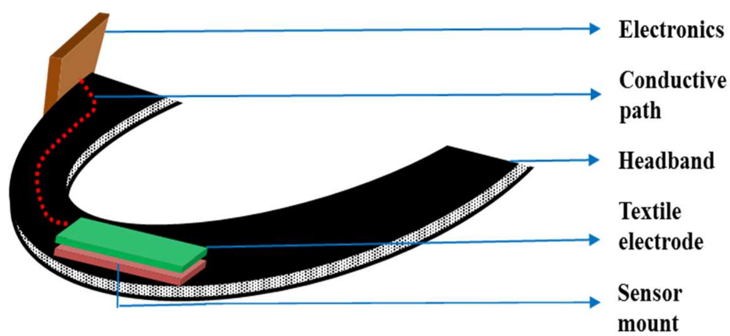

Figure 3: Headband and sensor architecture

Amplification and processing module

EEG and EOG are bio potential differential signals which are always measured by the potential difference between two points in a human body. The amplification module was designed with a large CMRR (Common Mode Rejection Ratio), small input offset voltage. A high CMRR is essential to isolate the amplifier from interferences from sources of noise. Similarly, a small input voltage is used to prevent voltage drifting at the output, thereby maintaining the signal quality. A single channel amplifier module was designed to amplify the raw EEG and EOG signals acquired by the sensor in the headband. Typically, the acquired bio-potential signals need to be amplified before they could be transmitted wirelessly. The first stage of the module consists of an amplifier with a high CMRR and input impedance. The other two stages of the module are used to increase the gain and to prevent signal degradation. The overall frequency of the amplifier was tuned to match both the EEG and EOG signals. The non-inverting amplifier after the first stage was implemented with the active filters to remove the aliasing artifact that may be created by the analog to digital conversion.

The amplified bio-potential signals are sent to the microprocessor for digitization and further processing. The two most important functions of the microprocessor are: (i) digitizing the amplified signal; and (ii) providing a control function to the Bluetooth module. Most of the commercially available processors are equipped with the analog-digital conversion units and timer registers, used to generate interrupts. This is used to set the interval based on the upper limit, which is preset based on the frequency of the count. Additionally, this trigger is also used as the trigger signal for the ADC (Analog to Digital Conversion) functionality. Serial communication is deployed to transmit the digitized signal to the Bluetooth transmitter module. And, UART (Universal Asynchronous Receiver and Transmitter) is used as the communication interface between the microprocessor and the Bluetooth transmitter [7]. Figure 4 shows the blocks involved in the system design, which covers the functionalities ranging from signal acquisition to signal transmission.

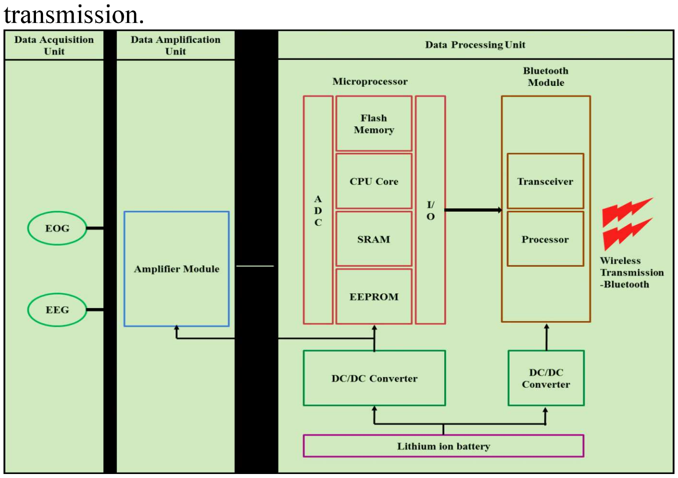

Figure 4: Data amplification and processing module

Transmitting module

Bluetooth was used as the communication medium to connect the headband to the monitoring station wirelessly. Generally, Bluetooth devices provide several profiles from which the user can choose the one that is best for the specific application. The profile chosen here was based on the type of data that were to be communicated. For instance, the analog-digital conversion output is in the form of digits and, hence, the serial port profile was used for this data set. This profile also provides continuous data transmission, which plays a pivotal role in this application. The Bluetooth transmitter can be connected with any Bluetooth-enabled device, provided the device is in the communication range and the correct security key is entered. Once the receiver satisfies these requirements, the receiver loaded with the software can diagnose the signal to perform the signal classification and feature extraction functions.

III. SOFTWARE DEVELOPMENT

Microprocessor programming

This part of the software is used to convert analog signals to digital signals at a fixed sampling rate; in addition, the software is designed to send the digital signal serially to the Bluetooth module. The A/D conversion is managed by the timer interrupt task, and the timer registers generate signals when the register value crosses zero; these generated signals are then used as triggers for the A/D conversion. The interval at which the interrupts are generated is fixed by setting the upper limit of the timer register. Since the interrupt is generated at a fixed interval, the A/D conversion can be performed periodically at the same fixed interval. The timer callback function, which offers the algorithm, is called on every 10 ms to acquire quantized data that has already gone through A/D conversion. The AT (attention) commands for communication are written in the microprocessor and the commands control the module through UART interface with 115,200 baud rate. The system needs to include a maintenance function in order to secure system reliability since it is possible to have a communication error in the wireless system. The maintenance function checks the status of the network before sending the data. In terms of the function, the data are saved in the RAM of the microprocessor for one-per-second record [8].

Receiver end programming

A software module was developed to filter, process, classify, feature-extract and monitor the signals transmitted by the headband. A laptop/computer can be used as a monitoring station. The entire code was developed in Matlab-2011. In addition, a user interface and a signal monitoring window were created to provide access as well as control to the software. The signal display window has 5 display channels, where it displays the raw EEG/EOG signal; blinks from the EOG signal; AR-PSD from EEG signal; mathematical values of number of blinks and the AR-PSD value; and the final discrimination (high level of drowsiness/drowsy/alert). The received signal was processed to extract the necessary features to discriminate drowsiness and alertness. The major features and functions of the software are as follows.

- **Feature extraction – EOG**

The raw amplified signals are received at the monitoring station via the developed user interface. The obtained EOG signals may have baseline fluctuations that are removed before the signal is further processed [9]. Then the peaks in EOG waveform are identified to differentiate slow/normal blinks. Figure 5 represents one of the initial experiments conducted to determine the peaks of the EOG waveform. These positive and negative peaks represent blinks and the frequency differences between the peaks, and are used to differentiate slow blinks from normal blinks to obtain the number of normal blinks in the given time period. The signal classifications are represented in figure 5.

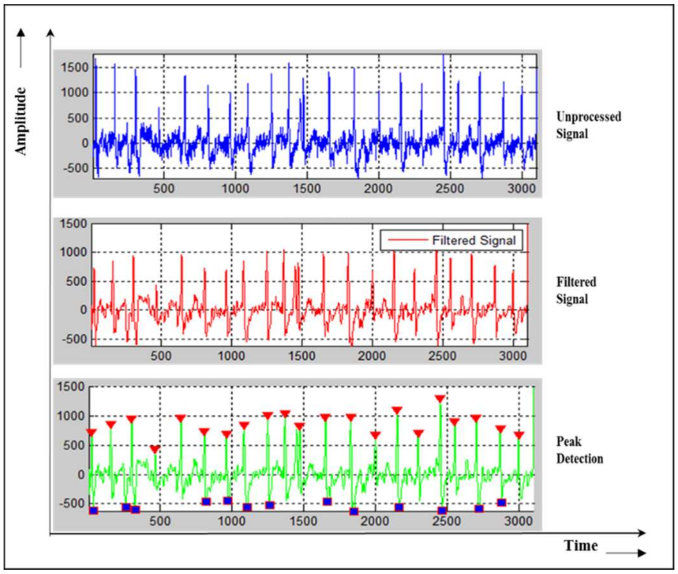

Figure 5: Feature extraction in EOG signal to characterize blinks

- **Classification – EEG**

The received EEG signals are obtained in the time domain and were converted to frequency domain to facilitate the AR-PSD function. This transformation was performed by using the Fast Fourier Transform algorithm. Generally, EEG waves consist of alpha, beta, gamma and theta bands. Here, AR-PSD was performed to find the peak position in any given period over the alpha band region (8-13 Hz) which indicates inattentiveness [10]. Similarly, the same function was performed over the beta frequency band region (13-30 Hz) to indicate attentiveness. Finally, the ratios of the obtained AR-PSD values in the respective frequency bands are calculated to final the numerical AR-PSD values. A solitary set of AR-PSD values obtained by following the above procedure is displayed in Figure 6.

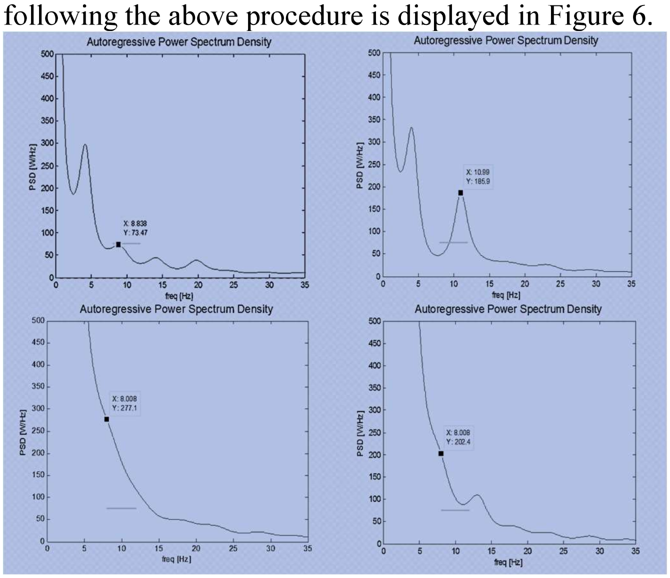

Figure 6: AR-PSD waveforms and peak values for open, normal blinking, closed, and slow blinking

IV. EXPERIMENTS, TESTS AND RESULTS

- **Comparison with Epworth sleep test**

Epworth Sleepiness Scale (ESS) is a self-administered questionnaire which is used to estimate the level of daytime sleepiness. It is scored in the range of 0-3, where 0 is the lowest degree of sleepiness while 3 is the highest. The subjects were asked to solve menial mathematical problems when the system was tested to calculate drowsiness. Additionally, the subjects were tested during daytime, with prescribed sleep deprivation levels that were a part of the test condition. Whenever the subject reported a score, the system was also tested alongside. Table 1 gives the test results and compares the present system results with those from the Epworth sleep test.

	Epworth Sleepiness Scale Score	**Calculated percentage of drowsiness**
Test 1	0	11.33%
Test 2	1	21.5%
Test 3	2	67.19%
Test 4	3	94.71%

Table 1: Comparison of ESS and the developed system

- **Comparison with Psycho-motor vigilance test**

An attention- and reaction-based timing test, called the psychomotor vigilance test (PVT), to analyze the reaction time of an individual at different test conditions was performed [11]. It is a sustained-attention, reaction-timed task that measures the speed with which subjects respond. This reaction time is then averaged over a number of attempts in a period of time to assess the level of attention of the persons in the given period of time. Research indicates that increased sleep debt or sleep inertia correlates with deteriorated alertness, slower problem-solving, declined psycho-motor skills, and increased rate of false responding. Table 2 gives the comparison results of the test conducted.

		TEST 1	TEST 2	Drowsiness percentage
NORMAL	No of times drowsiness was detected out of 24 times: PVT reaction time:	2 409 msec	2 397 msec	8.6 %
20 Hours Sleep Deprived	No of times drowsiness was detected out of 24 times: PVT reaction time:	12 533 msec	14 578 msec	60.4 %
28 Hours Sleep Deprived	No of times drowsiness was detected out of 24 times: PVT reaction time:	21 675 msec	19 654 msec	82.8 %

Table 2: Comparison of PVT and the developed system

- **Validation with a Driving simulator**

A Scania driving simulator was used to emulate real time application of this system where subjects were trained to drive a vehicle in the simulator [12]. Subjects were asked to maintain a specific sleep cycle to test the system under various conditions. To be precise, the subjects were tested when they were in normal condition, 20 hours sleep-deprived condition, and 28 hours sleep-deprived condition. The number of crashes under each test is noted along with the number of times drowsiness was detected. Each driving simulation test was run for 2 minutes, which allowed for a maximum detection of 24 instances, since drowsiness is estimated every 5 seconds. Table 3 shows the values tabulated for each test condition.

Condition	Subject	Number of crashes reported by the simulator	Number of times drowsiness was detected
Normal	Subject A	7	4
	Subject B	9	5
20 hours sleep deprived	Subject A	19	14
	Subject B	17	17
28 hours sleep deprived	Subject A	32	22
	Subject B	29	21

Table 3: Comparison of driving simulator and the developed system

V. DISCUSSIONS AND CONCLUSION

The wearable flexible headband system was developed along with the monitoring software to monitor a person's condition, especially drowsiness. The system was developed in such a way that it discriminates between drowsiness and alertness. The textile electrode and the electronics module continuously acquires and transmits the signals through the Bluetooth module to the monitoring station. The software deployed in the monitoring station decodes the signal into meaningful information where detection of alertness and drowsiness takes place. Several initial experiments were performed to estimate blink rates and AR-PSD of the EOG and EEG signal respectively. A correlation between EEG and EOG was derived especially using a differentiation in the blinks. Slow blinks, normal blinks, closed eyes, and open eyes are extracted from the EOG signal and correlated with the AR-PSD of EEG signal. Then these initial experiments were used as a basis to determine the decision and threshold criteria to estimate drowsiness. The derived decision criteria were deployed in the final display function of the software to exhibit the discriminated factor. Therefore effective discrimination between drowsiness and alertness is realized. The test results are proven and validated through comparison against various tests which estimate drowsiness. A few of the major challenges experienced in developing a real time monitoring system to detect drowsiness and alertness are: discriminating sleepiness/wakefulness; correlating EEG and EOG; developing a wearable system; validating and qualifying the system against the present techniques; and developing EEG/EOG based parametric decision criteria. Nonetheless, the present technological design of the proposed system can be used as a prototype for embellishing the design by introducing advancements and modifications in it in the future. These modifications may include other structural designs, communication protocols, software developments, power reduction techniques, to help improve the system performance.

VI. ACKNOWLEDGEMENTS

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Mouli Ramasamy was born in Coimbatore, India, in 1988. He received the B.E. degree in electronics and communication engineering from the School of engineering, Saveetha University, India, in 2011, and the MSEE degree in electrical engineering from the University of Arkansas, USA, in 2013. He is currently pursuing his doctoral degree in electrical engineering in the University of Arkansas. In 2011, he joined the University of Arkansas as a Visiting Research Scholar. Later in the same year he joined HCL Technologies, India, as a Software Engineer. During his stint as a Software Engineer, he was also involved with the healthcare software research in IIT (Delhi). His current research interests include wearable electronics and healthcare, Point of Care System, Nano-bio-sensors, pattern recognition, electrophysiology of the brain, bio-potential signal processing and Real time patient monitoring. He was the recipient of the Prolific Young Researcher Award from the Signal and Telecommunications department of Southern Railway in 2009. In 2010, he led at a team of 5 in the AUTCUP-Robotic Conference, Iran, to receive the Best Technical Aspect Award.

Sechang Oh received B.S. and M.S. degree in Electrical Engineering from Kyungpook National University, Korea in 1996 and Pohang University of Science and Technology, Korea in 1999. He received his PhD degree in electrical engineering from the University of Arkansas in 2013. From 1999 to 2008, he worked for the LG INNOTEK Co., Ltd., where he was involved in the development of wireless communication modules and electronic devices. He was involved in the development of a wireless network camera using motion detection, audio/video recording, single packaged Wi-Fi module based on LTCC, dual band WiMAX module, Wibro/Wi-Fi combo module, CDMA (KPCS) full module, Wi-Fi mini PCI card, IF SAW filters, and 915 MHz VCSO during his tenure at LG INNOTEK Co., Ltd., He has 14 pending patents on his research in Korea. Currently, he is a Research Associate in the Department of Electrical Engineering, University of Arkansas, Fayetteville. His research interest includes biomedical nano-sensors and wireless sensor systems for real time monitoring of pathophysiological changes in the body, wireless health monitoring systems, Point-of-Care health diagnostic systems, biomedical pattern recognition, Human Computer Interface, antenna/RF/mobile system design, energy harvesting for self-powered systems.

Professor Vijay Varadan is currently the Twenty First Century Endowed Chair in Nano-and Bio-Technology and Medicine, and Distinguished Professor of Electrical Engineering, and Distinguished Professor of Biomedical Engineering (in College of Engineering), and Neurosurgery (in the College of Medicine) at the University of Arkansas. He is also a Professor of Neurosurgery at Penn State University College of Medicine.

He joined the University of Arkansas in January 2005 after serving on the faculty of Cornell University, Ohio State University and Pennsylvania State University for four decades. He is also the Director of the Center of Excellence for Nano-, Micro-, and Neuro-Electronics, Sensors and Systems.

He has concentrated on the design and development of various electronic, acoustic and structural composites, smart materials, structures, and devices including sensors, transducers, Microelectromechanical Systems (MEMS), synthesis and large scale fabrication of carbon nanotubes, NanoElectroMechanical Systems (NEMS), microwave, acoustic and ultrasonic wave absorbers and filters.

He has developed neurostimulator, wireless microsensors and systems for sensing and control of Parkinson's disease, epilepsy, glucose in the blood and Alzheimer's disease. He is also developing both silicon and organic based wireless sensor systems with RFID for human gait analysis and sleep disorders and various neurological disorders.

He is a founder and the Editor-in-Chief of the Journal of Smart Materials and Structures. He is the Editor-in-Chief of the Journal of Nanomedical Science in Engineering and Medicine. He is an Associate Editor of the Journal of Microlithography, Microfabrication and Microsystem. He serves on the editorial board of International Journal of Computational Methods. He has published more than 500 journal papers and 14 books. He has 13 patents pertinent to conducting polymers, smart structures, smart antennas, phase shifters, carbon nanotubes, and implantable device for Parkinson's patients, MEMS accelerometers and gyroscopes. He is a fellow of SPIE, ASME, Institute of Physics, and Acoustical Society of America. He has many visiting professorship appointments in leading schools overseas.

Robert Harbaugh was born in West York, Pennsylvania on April 5, 1952. He graduated from high school in Red Lion, Pennsylvania in 1970 and obtained a BS degree from Lebanon Valley College in 1974. Dr. Harbaugh obtained his M.D. from the Pennsylvania State University College of Medicine in 1978 and received his general surgery and neurosurgery training at Dartmouth from 1978-1985. He was appointed Assistant Professor of Surgery (Neurosurgery) at the Dartmouth Medical School in 1985 and progressed to the rank of Professor of Surgery (Neurosurgery) in 1997 and Professor of Radiology in 2001. During his career at Dartmouth, Dr. Harbaugh served as Director of the Dartmouth-Hitchcock Medical Center Cerebrovascular Disease Center from 1994-2003, Director of Cerebrovascular Surgery from 1989-2003, Director of the Neurosurgical Laboratory from 1985-1997 and as acting Residency Program Director from 1996-1997.

In 2003 Dr. Harbaugh returned to Pennsylvania as Professor and Chairman of the Department of Neurosurgery, Neurosurgery Residency Program Director and Professor of Engineering Science and Mechanics at the Pennsylvania State University. He has recently been recognized as a Penn State University Distinguished Professor (Penn State's highest academic honor) and has been chosen to serve as the Director of the new, university-wide, Penn State Institute of the Neurosciences.

Dr. Harbaugh has been an invited speaker in eleven different countries and throughout the United States. His present research interests include clinical trial design, outcomes analysis and quality improvement in neurosurgery and computer modeling of intracranial aneurysms. He maintains a busy clinical practice specializing in cerebrovascular surgery and tumor surgery.

Dr. Harbaugh has edited three books and published more than 230 articles, book chapters and abstracts. He has served on the editorial boards of Neurosurgery, the American Association of Neurological Surgeons Bulletin, Neurosurgery On Call, the Journal of Neurovascular Disease, the Journal of Neuropsychiatry and Clinical Neurosciences and Neurobiology of Aging. Dr. Harbaugh has obtained funding for 13 grant proposals from the NIH, NATO, USDA, industry and foundations. He has two U.S. patent applications.

He is a member of the AANS, CNS, the American Academy of Neurological Surgery, the SNS, the AANS/CNS Section on Cerebrovascular Surgery (SCVS), the AANS/CNS Tumor Section, the American Stroke Association (ASA), the American Heart Association (AHA) Stroke Council, the New England Neurosurgical Society (NENS), the Pennsylvania Neurosurgical Society (PNS) and the American College of Surgeons (ACS). He has held numerous leadership positions in these organizations including Chair of the SNS Membership Committee, Scientific Program Chair for the Academy, Director-at-Large of the AANS Board of Directors, Chairman of the AANS Digital Technology Committee, Chairman of the AANS/CNS Committee for the Assessment of Quality, Chairman of the AANS/CNS Outcomes Committee, Chairman of the AANS/CNS Quality Improvement Workgroup, Chairman of the AANS/CNS Washington Committee and Member of the Executive Committee and Annual Meeting Chairman of the PNS. Dr. Harbaugh is a Fellow of the ACS and the AHA. He served as a member of the Leadership Committee of the AHA Stroke Council, as Chairman of the SCVS from 2002-2003 and President of the NENS from 2001-2003. He is also the President of the NeuroPoint Alliance, Inc. and CHYNA, LLC.

Editorial Comment

Future directions in the development of "small antennas" clearly point to the design of various sensors, including those in the area of healthcare monitors. In this paper Varadan, who is well known for his extensive contributions in the field of RF sensors for biological monitoring, presents a real-world design of textile-based sensors for monitoring drowsiness while driving, to help mitigate the problem of automobile accidents caused by driver drowsiness.